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Developments in Utilization of CCPs in Ohio

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# Developments in Utilization of CCPs in Ohio


***Abstract***

*With approximately 90% of Ohio's electricity being generated from the burning of coal, the state generates approximately 11.6 million tons of coal combustion products (CCPs) annually. In the past, most of these CCPs have been put in landfills, resulting in largely non-productive disposal of these materials. The utilization of CCPs as raw materials for civil engineering, mineland reclamation and agricultural applications that are technically sound, environmentally benign and commercially competitive, will make possible (1) a decrease in the need for landfill space, (2) conservation of the natural resources of the state, (3) a continuation of the use of Ohio's high-sulfur coal, (4) significant economic savings for end users, and (5) reduced overall cost of generating electricity. This paper reviews the progress made in the last few years in CCP research by discussing a number of demonstration projects conducted in Ohio to promote the utilization of CCPs. A comprehensive overview of the utilization technologies successfully developed and implemented in the state as well as those under development is presented. A CCP pilot extension program, the first of its kind in any state of the US, which was established at The Ohio State University, is discussed.*


## Introduction

More than half the electricity produced in the US is generated by coal fired utilities. According to the American Coal Ash Association (Stewart, 1997), in 1996 approximately 800 million metric tons of coal was burned in the US to produce electricity. The Clean Air Act Amendments of 1990 required many utilities, especially those in the Midwest, which burn high-sulfur bituminous coal, to reduce sulfur dioxide emissions. This has resulted in the generation of large amounts of coal combustion products (CCPs), over 100 million tons annually (Stewart, 1997), which could possibly be beneficially utilized. These CCPs include fly ash, bottom ash, boiler slag, and flue gas desulfurization (FGD) material. Only one-fourth of these CCPs were utilized while the rest were disposed mainly by landfilling. Only 7% of the FGD material generated in 1996 was utilized and that largely by the wallboard industry. With phase 2 of the Clean Air Act Amendment of 1990 going into effect soon, the amount of FGD material alone produced in the US may increase to almost 200 million tons, thus exceeding the production of other CCPs (Kalyoncu, 1996).

In Ohio, nearly 90% of the electricity produced is generated by burning coal, and the state generates about 12% (approximately 11.6 million tons) of all CCPs produced in the US. Approximately 4 to 6 million tons of FGD material are generated annually in Ohio. The utilization of these coal combustion products as raw materials in applications that are environmentally sound, technically safe and commercially competitive should lead to a reduction in the landfilling of these products. The utilization of CCPs as raw materials in civil engineering / highway construction, mineland reclamation and agricultural applications will result in:

- Decrease in the need for landfill space
- Reduced environmental effects of landfill disposal
- Conservation of natural resources (e.g. clay, stone aggregate)

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- Cleaner and safe environment
- Reduced carbon dioxide emissions
- Continuation of the use of Ohio's high-sulfur coal
- Significant economic savings for end users
- Boost economic development
- Reduced overall cost of generating electricity.

This paper summarizes the research conducted in Ohio on the utilization of CCPs. An overview of the past and current demonstration projects is presented. A technology transfer and market study pilot extension program currently underway at The Ohio State University is discussed.

**Research on Utilization of CCPs in Ohio**

Over the last nine years, Ohio has become a leader in the development of new technologies for uses of CCPs. This is the result of tremendous cooperation and support by a large number of organizations including: the Ohio Coal Development Office within the Ohio Department of Development, The Ohio State University, US Department of Energy, American Electric Power, Ohio Edison, Dravo Lime Company, Electric Power Research Institute, US Geological Survey, Ohio Department of Natural Resources, Ohio Environmental Protection Agency, American Coal Ash Association and others.

Several researchers at The Ohio State University participated in a long term study aimed at characterizing the physical, chemical, mineralogical and engineering properties of dry and wet FGD material and its land application (Stehouwer *et al.*, 1995a, 1996, 1998, Wolfe *et al.*, 1992, Adams *et al.*, 1992, Beeghly *et al.*, 1993, 1994, 1995b, Wolfe and Cline, 1995, Dick, *et al.*, 1997,1998). An extensive review of the state of the art for the characterization and utilization of FGD material was performed (Stehouwer *et al.*, 1995a, 1998, Dick *et al.*, 1998). Samples were collected from 13 different coal-fired boilers and representative samples of FGD technologies being tested in Ohio were selected for detailed analysis. The technologies included Lime Injection Multistage Burners (LIMB), Pressurized Fluidized Bed Combustion (PFBC), Spray Dryer and Duct Injection. The engineering properties of compacted FGD that were studied included optimum moisture content, density, compressive strength, compressibility, permeability, and swelling potential. These engineering properties were identified to be critical in the design and construction of high volume engineered fills, highway embankments and other earth structures that might be made of compacted FGD. Several other land applications of FGD including mine reclamation, agricultural liming substitute and alkaline amendments for strip mine reclamation were identified and studied. The social costs and economic benefits of CCP utilization were presented by Hite (1994) and Hitzhusen (1992).

The swelling potential of FGD was studied by Adams (1992) and Adams and Wolfe (1993) by conducting long-term laboratory swell tests on more than a dozen samples from four power plants representative of FGD processes. Two distinct swelling episodes were observed. The first episode occurred almost immediately after water was supplied to the specimens. This corresponds with the time period during which naturally occurring soils typically experience greatest volume increases due to hydration reactions. The second episode of swelling was observed to begin after 10 or more days had elapsed. A study of the occurrence of swell along with mineralogical changes in FGD material was presented by Stehouwer *et al.*, 1996.

The effects of freeze-thaw cycling can be quite significant in Ohio. Hargraves (1994) and Chen *et al.* (1997) investigated the effect of thermal cycling on the strength of compacted wet FGD material. Higher water content samples exhibited greater reduction in compressive strength due to freeze-thaw cycling. It was observed that high strengths could be maintained under freeze-thaw cycling if at least 5% lime (dry weight basis) was added to the FGD before compaction and the material allowed to cure for 60 days before being exposed to freeze-thaw. These general recommendations are now used in guidelines for the structural use of FGD in Ohio.

For the use of FGD in highway construction applications, the effect of freeze-thaw cycling on the resilient modulus of PFBC material can be quite significant. Roy (1994) and Wolfe *et al.* (1997) found that dry FGD products subjected to freeze-thaw cycling could be used satisfactorily as a subgrade material in the construction of low traffic volume roads. Favorable comparison of FGD moduli with published values for materials commonly used in road base construction were seen.

The suitability of dry and wet FGD material as an impervious liner in place of commonly used clay was investigated by Kim *et al.* (1992a) and Butalia and Wolfe (1997). Characterization of stabilized FGD showed that laboratory samples could be compacted to achieve permeability coefficients lower than the value typically required by EPA for lining waste containment facilities ($1 \times 10^{-7}$ cm/sec). Low permeabilities were measured for samples with high fly ash to filter cake ratio (2:1) and high lime percentage (8%).

**Ohio Demonstration Projects**

Laboratory tests are typically carried out in a controlled environment under conditions that are generally not the same as those in the field. The obvious next step in the process of characterizing the behavior of FGD would be to conduct field demonstration projects to study the suitability of the material and its performance, before a particular utilization technology can be made commercial for the end user. The Ohio Coal Development Office within the Ohio Department of Development has sponsored many of the field demonstration projects that have been carried out in Ohio. A brief description of these project follows.

***Truck Ramp***

The purpose of constructing a truck ramp was to evaluate the field handling and compaction characteristics of spray dyer ash. The ramp (17 meter long by 7.5 meters wide and 1.2 meters high) was designed by Ohio State University's Department of Physical Facilities to provide a location for unloading hard trash (Wolfe and Beeghly, 1993). The ramp was constructed by university maintenance personnel during work schedule breaks in the summer of 1992. A spray dryer ash from the university's McCracken power plant was used as the primary construction material. The ash was placed within 5% of the optimum moisture content and greater than 90% standard Proctor densities were achieved. The ash did not require any special handling and was constructed using university owned equipment. Tests performed on samples cored from the ramp showed that after a year of service, the water content was considerably higher than the optimum moisture content. Unconfined compressive strength tests conducted on samples cored from the ramp exhibited lower strengths than those achieved in the laboratory. Despite the difficulty in achieving uniform conditions during construction, the ramp has performed well with no evidence of failures during subsequent use by university vehicles.

### *Livestock Feedlot & Hay Storage Pads*

In high rainfall areas such as Ohio, it is desirable to pave livestock feedlot areas with a durable material like concrete or rock aggregates. Otherwise animals expend considerable amount of energy just to move through slushy organic soil. An inexpensive and reliable technique for stabilizing the feedlot floors was identified to be the use of compacted FGD. The site chosen for the first FGD cattle feedlot demonstration project was the Eastern Ohio Resource Development Center in Belle Valley, Ohio. Dry cyclone ash from AEP's PFBC Tidd plant was used to stabilize the saturated organic in-place soil. The ash was blended into the top 1 ½ feet of the soil and the mixture was compacted to produce a stabilized base. A 1 ½ -2 ½ feet thick layer of compacted ash was then put on top of the stabilized base. All the construction activities were performed by farm personnel using standard farm equipment. Some minor failures were observed when the first round of cattle was brought onto the feedlot. However since the repair of these minor failures, the feedlots have performed well. Additional livestock feedlots and hay storage pads were constructed at the EORDC farm in September of 1993 using wet FGD from AEP's Conesville plant. These feedlots have performed very well with an approximately ½ to 1 inch annual wear. Ohio EPA was satisfied with the performance of the FGD feedlots and hay storage pads and American Electric Power currently has a state wide blanket permit to install (PTI) FGD livestock feedlot and hay storage pads using lime enriched FGD material from Conesville and Gavin power plants. As long as the conditions in the PTI are met and the thickness of FGD layer is less than 15 inches, no additional approval from Ohio EPA is necessary. The construction of FGD feedlots does not require any special equipment. The cost of an FGD feedlot can be up to 25 percent less than the estimated cost using aggregate and approximately 65 percent less than the estimated cost of concrete. AEP's plants have generally provided the material free of cost at the plant with farmers paying for hauling costs. In some cases, the plant has been willing to truck the material to the site if it is in vicinity of the plant. In the summer of 1997, a total of 24 livestock feedlots and hay storage pads ranging in size from 1,500 $ft^2$ to 14,000 $ft^2$ were constructed in southern and eastern Ohio. Because of the success of these pads, livestock feedlots and hay storage pads constructed with FGD material are in high demand in some parts of Ohio. More than 100 FGD pads are expected to be installed in 1998.

### *Highway Embankment Repairs*

A section of Ohio State Route 541 located west of Coshocton that was failing due to a rotational slide was stabilized in the winter of 1993 using PFBC ash generated by AEP's Tidd plant. The portion of the road affected by the slide was constructed in 1966 over a large fill. The first phase of the project involved the excavation of approximately 310,000 $ft^3$ of soil from above the slip plane. Half of the excavated soil was stockpiled for later use at the site while the rest was transported off site. Several under drains had to be constructed to direct water away from the load bearing portions of the embankment. The second phase involved the placement and compaction of FGD material. Self-loading scrapers delivered the material stocked onsite, as bulldozers spread it evenly over an area 40 feet wide and 100 feet long. The first lift was approximately 2 feet thick and was placed and compacted in one day. Within 12 hours of placement the FGD had gained enough strength for the scrapers to drive over it without leaving any tire tracks. The FGD buttress was constructed up to a height of 13 to 16 feet. The thickness of layers and the amount of water added to the FGD were not strictly monitored. It was observed that the material had a wide workable range and did not have to be mixed with laboratory precision to yield excellent strengths. The original embankment material was then placed on top of the FGD buttress in controlled lifts and the final road surface was constructed. During the first and second phase of the embankment repairs, regular monitoring of the water quality upstream and downstream of the project was done. The variations in pH and total dissolved solids were within the acceptable range of fluctuations associated with the stream. However, water samples taken from underdrains showed a significant rise in sulfates and total alkaline measured as $CaCO_3$. The volume of stream flow was so much greater than the volume of water being expelled through the underdrains that the total system appeared unaffected by the increase in measured sulfates and $CaCO_3$ in the leachate. Long-term water quality monitoring of the site is being continued through the third phase of the project. A system of inclinometers, piezometers and deformation measuring gauges were installed at the site and are regularly monitored by ODOT personnel. A more detailed description of the project was presented by Nodjomian (1994), Nodjomian and Wolfe (1994) and Kim *et al.* (1995).

A second highway embankment repair project involved the stabilization of a portion of Ohio State Route 83 south of Cumberland. A section of the road that had been damaged due to repeated rotational slides was reconstructed using Tidd PFBC ash in 1994. The first phase of the project involved excavation of approximately 380,000 $ft^3$ of embankment soil. Fabric drain boards were installed in a trench dug along the hillside to prevent groundwater from reaching the embankment. The trench was backfilled with compacted FGD in approximately 1 foot thick lifts using a small bulldozer for spreading and a sheepsfoot roller for compaction. The second phase of the project was begun by dividing the embankment into four separate sections. Control sections were established at the north and south end of the site. The control sections were repaired according to standard ODOT procedures by drying, replacing and compacting the stockpiled soil. One test section consisted of a mix of Tidd ash and onsite soil while the third section was constructed using only the ash. The ash-soil section was compacted in lifts of about 8 inches thick while the ash only section could be compacted with much thicker lifts ranging from 1 to 2 feet. Strict control was kept on the moisture content and compacted density and approximately 95% compaction using the standard Proctor was achieved for the four sections. The embankment construction was completed in December of 1994. However, because asphalt plants had closed down for the season, one half of the road was constructed with a 1.5 feet thick compacted FGD wearing course while the other half was made with a 1.5 feet thick layer of stone aggregate. The road was opened to traffic in late December. The ash has performed well over the last four years and has not needed any repairs. Water around the embankment has shown no indication of metals leaching into the surrounding environment. More details on the Ohio SR83 project can be found in Payette *et al.* (1997) and Civil Engineering News (1997).

The results from these two studies indicated that laboratory precision was not required to achieve excellent strength properties that were more than sufficient for road repair. In order

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to facilitate the use of FGD in highway embankment repairs, a knowledge-based expert system was developed by Kim *et al.* (1992b, 1993, 1994).

High volume uses of CCPs such as those for highway embankment applications generally require temporary stockpiling of the material onsite. A 1,500 ton pile of dry LIMB FGD material was constructed in 1992 at a moisture content approaching the optimum water content of 40-50% (Beeghly *et al.*, 1995a). The changes in the properties of the pile were studied for 30 months. Hydration reactions formed gypsum and ettrengite creating a crust that stabilized the surface of the pile. This prevented dusting during dry periods and also reduced erosion from the slopes of the pile. However, the runoff from the slopes was minimal. By allowing for the formation of some ettrengite to proceed, the expansion of an embankment after placement and compaction of FGD could be minimized. But this would result in a decrease in the cementious capacity of FGD. However, the addition of a small amount of lime just prior to placement should help overcome the loss of cementious reaction that occurred during storage.

***Surface Reclamation of Abandoned Mined Lands***

Laboratory investigations into the use of FGD for mine reclamation applications were carried out by Sutton and Stehouwer, 1992, Stehouwer *et al.*, 1993 and Soto *et al.*, 1993. Greenhouse column studies were carried out by Stehouwer *et al.* (1995b) to study the element solubility and mobility characteristics of amended minespoils while Stehouwer *et al.* (1995c) studied the plant growth in minespoils amended with dry FGD. Issues relating to the extension of laboratory tests to field demonstration of minespoil amendments were presented by Dick *et al.*, 1994a.

Several field demonstration projects have been conducted in Ohio that have studied the use of FGD material for reclamation of highly degraded abandoned mines. An abandoned clay and coal mine near Dover commonly referred to as the Fleming demonstration site was regraded in summer of 1994 and three types of amendment treatment were applied in fall of 1994. The treatment schemes included separate equivalent applications of limestone, FGD material (PFBC) and a 2.5:1 mixture of FGD and yard waste compost. The treatments were incorporated to a depth of approximately 8 inches. Surface water and drainage water samples were collected. Arsenic was found to be the only trace element that approached a level that would preclude the use of FGD for mine reclamation. The concentrations of all other elements were below the regulation concentrations or loading limit. It was observed that often these metal concentrations were lower than those in the existing overburden spoil that required reclamation. All three treatments improved water quality. The concentration of Boron in the leachate was particularly high from the FGD plots but was below the phytotoxic levels. Surface water quality has remained almost unchanged from 1995. All treatments resulted in water pH of approximately 7. The drainage water samples collected in spring of 1995 showed the FGD plots were neutral while others were acidic (pH of 4-5.5). In July of 1996, the pH values of the treatments whose pH had declined earlier, rose to the neutral level. All the treatments provided complete ground cover. However, all treatments showed a decline in the vegetative growth in 1996 as compared with 1995 with the decline being the greatest for lime treated plots. Long-term effectiveness of the FGD treatments is being studied at the site to learn more about the ecological sustainability of these materials.

Additional mine reclamation field-testing was carried out at Unit II of the Eastern Ohio Resource Development Center near Caldwell, in Southeastern Ohio. The aim of the project was to evaluate the reclamation performance of two wet FGD materials and compare them with borrow soil and sewage sludge minespoil amendments. The two types of FGD materials used in this demonstration project were generated by the wet lime scrubbers of AEP's Conesville plant and an experimental scrubber at Cinergy's Zimmer plant. The original field plot sites had low levels of extractable nutrients. The site was regraded in summer of 1995 and treated with six different types of mine soil amendments. These treatments included: 1) sewage sludge, 2) gypsiferous Zimmer FGD, 3) Conesville FGD, 4) Zimmer FGD mixed with sewage sludge, 5) Conesville FGD mixed with sewage sludge, and 6) red silty clay borrow soil. Details on the applications rates were presented by Kost *et al.* (1997). All the amendments were rototilled to a depth of about 30-cm. These treatments were applied in the fall of 1995. A flume was installed at the bottom of each plot to collect surface water runoff. Appropriate fertilization of the plots was carried out and they were seeded in fall of 1995 with winter wheat cover crop, and a mix of birdsfoot trefoil, red clover, perennial ryegrass and timothy. Ten seedlings each of white ash, black locust, sycamore and sweetgum were planted in spring of 1996 in each plot. Tree survival, tree height, biomass cover, soil and water quality were monitored. Preliminary results (Kost et al., 1997) of samples collected at the site indicate that all amendments except the sewage sludge alone are effective in decreasing soil acidity within the zone of incorporation. Vigorous herbaceous cover has existed on all the treatments for two years. During this time, herbaceous biomass was reported to be the greatest for plots that were treated with a mixture of Conesville FGD and sewage sludge (Kost, 1997). Additional observations and conclusions for these demonstration projects can be found in Dick *et al.*, 1994b and Stehouwer and Dick, 1997.

***Agricultural Liming Substitute***

FGD holds good promise as a substitute for conventional agricultural lime to adjust the pH of soils (Dick *et al.*, 1993, Sutton *et. al*, 1994, Stehouwer *et al.*, 1995d). The neutralizing potential of FGD is due to the presence of calcium carbonate and calcium hydroxide. FGD with a total neutralizing potential of 60% CCE (calcium carbonate equivalency) was used as a limestone substitute at two different Ohio sites. The first field test was conducted at a highly acidic site (pH of approximately 4.6) near Wooster. The amount of PFBC FGD ash applied to the site was varied from 0, 0.5, 1 and 2 times the lime requirement rate as determined by standard soil tests. The FGD ash was applied in the fall of 1992 and alfalfa was planted that season, while corn was planted in spring of 1993. Alfalfa yields increased rapidly compared with untreated control. Corn yields were not significantly increased with the use of PFBC ash. The concentrations of Boron in alfalfa tissue were high for the FGD plots but were below the phytotoxic levels. Tissue concentrations of aluminum and manganese decreased for all samples. Soil acidity was neutralized in the zone of application (0-4 inches) and within one year the pH correction had extended to a depth of about 12 inches. In 1997, another field experiment was begun in Wooster using a sorbent FGD that contained clay. The CCE of the FGD was 46% and it was applied in the spring of 1997 at a rate based on standard soil tests. Alfalfa was planted on the plots. Sorbent FGD significantly increased alfalfa yields as compared to untreated control plots. The yields were more with the sorbent FGD than when the soils were amended with agricultural limestone. This benefit may be due to the presence of trace elements in the FGD material as well as its neutralizing potential. The plots are being monitored to evaluate their long-term performance.

Laboratory and field tests have shown that FGD materials with low boron content, low soluble salt content and high acidic neutralizing potential can be utilized as a soil amendment in place of agricultural limestone. Weathering of FGD prior to application results in lower boron and salt content but decreases its neutralizing potential. Application of FGD to the soil using a conventional limestone spinner spreader can cause excessive dusting due to the fine fly ash particles. A drop box spreader can be used instead for spreading the FGD or it could be mixed with other amendments such as organic matter and incorporated into the soil.

***Low Permeability Liner***

In order to evaluate the performance of FGD as a liner for manure holding facilities, ponds and wetlands, a full-scale pond facility was constructed in the summer of 1997 at the Ohio State University's Ohio Agricultural Research and Development Center near South Charleston. The pond capacity is approximately 150,000 cubic ft. and the facility was constructed using wet FGD as the primary liner. The FGD material used for the project was generated by AEP's Conesville plant using lime slurry injection. A total of approximately 2700 tons of FGD material was compacted in 4-6 inch lifts to obtain an 18 inches thick FGD liner. The design and construction of the FGD-lined facility was presented by Butalia, *et al.* (1997) and Wolfe and Butalia (1998). First year monitoring of the facility indicates (a) small amount of water is leaching through the field compacted FGD liner (permeability coefficients using full-scale tests are in the range of $10^{-7}$ cm/sec), and (b) quality of the leachate generally meets the National Primary Drinking Water Regulations (Wolfe *et al.*, 1999). The water in the pond is being replaced with swine manure in September 1998 and the site will be monitored for at least one more year.

***Abatement of Acid Mine Drainage***

Acid mine drainage (AMD) from abandoned underground coal mines in Ohio causes significant contamination to area streams and lakes. A small abandoned deep mine commonly referred to as Robert-Dawson mine near Coshocton, Ohio was chosen to study the technical feasibility of injecting cementitious alkaline materials such as FGD into the mine to reduce the environmental degradation occurring due to AMD discharge into the local stream. The effluent at the mine entrances had a low pH (2.8-3.0). Wet FGD generated by AEP's Conesville plant was pressure grouted into the mine through vertical grout injection holes during the winter of 1997-98. The FGD injection was carried out using regular grouting equipment. Approximately 26,000 tons of FGD material was estimated to be pumped into the underground mine. Two types of FGD grouts were injected into the mine. A thicker mine seal mix (slump of 4-6 inches) was used to seal the down dip areas. The intent was to flood the mine behind the plug so that the water level behind the seal would rise above the coal seam. This would lead to a reduction in AMD production, as no oxygen would be available to oxidize the pyrites in the coal. A similar but much more fluid (slump 8-10 inches) grout mix was injected in some of the up-dip areas of the mine. This was done to neutralize the acidic water in the mine and to coat the bottom of the mine with FGD to cover the pyrite material. A detailed description of the Robert-Dawson AMD abatement project was presented by Mafi *et al.* (1997). Monitoring of the surface and ground water is being conducted to evaluate the impact of FGD injection inside and outside the deep mine.

***Construction Aggregate***

A program to investigate the technical and economic feasibility of making construction-grade aggregates from wet FGD is under progress by CONSOL. The characterization and bench scale pelletization of FGD material have been completed. The results of this study have shown that products meeting all AASHTO specifications for Class A highway construction aggregates and products meeting important ASTM specifications for lightweight aggregate can be produced from wet FGD material. The synthetic aggregates were produced using CONSOL's disk pelletization technology. A large amount of synthetic aggregate will be produced this year that will be used in two field demonstration projects. The first project will involve the construction of a bituminous paving test patch with the synthetic aggregate and the second will be the construction of a mine stopping wall using lightweight blocks. The durability of the road aggregate and structural integrity of the lightweight blocks will be monitored.

**Ohio Pilot Extension Program**

Recent research and demonstration projects in Ohio have shown that CCPs can be utilized with proper preparation and oversight. A pilot technology transfer and market development program was established in January 1998 at The Ohio State University. The CCP pilot extension program is the first of its kind in any state in the US. It aims to move technologies for utilization of CCPs (particularly FGD material) from the research and demonstration phase into the marketplace with the establishment of a statewide Coal Combustion Products Coordinator. Bringing CCP use technology to the marketplace has both economic direct benefits and indirect and societal benefits for Ohio. The direct benefits are most easily quantified and are generally what drive the adoption of a new product or technology. Direct economic benefits include those realized by both the producer of the CCPs and the end user. The producer benefits if the cost associated with support of beneficial uses is lower than that of landfilling or other disposal means. The end user benefits if the CCP application results in lower cost than conventional application. The CCP Coordinator acts as a liaison among the parties interested in CCP use, producing fact and information sheets and providing expertise in the field to those who wish it. The Coordinator also sponsors or co-sponsors seminars, meetings, and speaking at these events, and generally works to promote knowledge about the productive and proper application of these products as useful raw materials. A significant component of this program is a market development study, which includes identification of CCP production in Ohio, and the estimated and potential markets for these CCPs particularly in highway/road construction and related civil engineering uses, mine reclamation and agricultural applications. The principal sponsor of the CCP pilot extension program is the Ohio Coal Development Office within the Ohio Department of Development. Other co-sponsors of this initiative are recognized in the acknowledgments. More information on the use of CCPs in Ohio and the pilot extension program can be obtained from the CCPOhio Internet web site at **http://ccpohio.eng.ohio-state.edu**

**Conclusions**

Laboratory and field demonstration research projects conducted in Ohio indicate that coal combustion products, particularly dry and wet FGD materials, can be favorably utilized in a safe and economic manner in highway construction, mine reclamation and agricultural applications. A pilot extension and technology transfer program is currently in progress in Ohio for bringing the utilization of CCPs to the marketplace.

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**References**

Adams, D.A., 1992, Swelling Characteristics of Dry Sulfur Dioxide Removal Waste Products, M.S. Thesis, The Ohio State University, Columbus, Ohio.

Adams, D.A., Wolfe, W.E., and Wu, T.H., 1992, Strength Development in FGD-Soil Mixtures, Proceedings of the 9th Annual Pittsburgh Coal Conference, Pittsburgh, Pennsylvania, October, 12-16, p. 224-228.

Adams, D.,A., and Wolfe, W.E., 1993, The Potential for Swelling in Samples of Compacted Flue Gas Desulfurization By-Products, Tenth American Coal Ash Association Symposium, Orlando, Florida.

Beeghly, J., Bigham, J., and Dick, W.A., 1993, An Ohio Based Study on Land Application Uses of Dry FGD By-Products, Tenth American Coal Ash Association Symposium, Orlando, Florida.

Beeghly, J., Dick, W., Harness, J., and Wolfe, W.E., 1994, Land Application Uses of Pressurized Fluidized-Bed Combustion (PFBC) Ash, Conference on Management of High Sulfur Coal Combustion Residues, Carbondale, Illinois, April.

Beeghly, J., Bigham, J., Dick, W., Stehouwer, R., and Wolfe, W.E., 1995a, The Impact of Weathering and Aging on a LIMB Ash Stockpile Material, Proceedings of 11th International Symposium on Use and Management of Coal Combustion By-Products (CCBs), Orlando, Florida, Jan 15-19, American Coal Ash Association and Electric Power Research Institute, EPRI TR-104657, V. 1.

Beeghly, J.., Dick, W.A., and Wolfe, W.E., 1995b, Developing Technologies for High Volume Application Uses of Pressurized Fluidized-Bed Combustion (PFBC) Ash, Proceedings of the International Conference on Fluidized Bed Combustion, ASME, V.2, p. 1243-1257.

Butalia, T.S. and Wolfe, W.E., 1997, Re-Use of Clean Coal Technology By-Products in the Construction of Impervious Liners, 1997 Ash Utilization Symposium, Lexington, Kentucky, October 20-22.

Butalia, T.S., Mafi, S., and Wolfe, W.E., 1997, Design of Full Scale Demonstration Lagoon Using Clean Coal Technology By-Products, 13th International Conference on Solid Waste Technology and Management, Philadelphia, Pennsylvania, November 16-19.

Chen, X., W.E. Wolfe and M.D. Hargraves, 1997, The Influence of Freeze-Thaw Cycles on the Compressive Strength of Stabilized FGD Sludge, *Fuel*, V.76, p. 755-759.

Civil Engineering News, 1997, Coal Combustion Product is Good for Highway Use, November.

Dick, W., Stehouwer, R., Sutton, P., Bigham, J., Lal, R., Traina, S., McCoy, E., and Fowler, R., 1993, Plant Growth and Soil Properties Responses to Additions of Dry Flue Gas

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Desulfurization By-Products, EPRI/USEPA $SO_2$ Control Symposium, Boston, Massachusetts, August 24-27.

Dick, W., Stehouwer, R., and Bigham, J., 1994a, Problems Getting From The Laboratory to The Field: Reclamation of an AML Site, Proceedings of the 11th Annual Pittsburgh Coal Conference, Pittsburgh, Pennsylvania, September 12-16, p. 451-456.

Dick, W., Stehouwer, R., Beeghly, J., Bigham, J., and Lal, R., 1994b, Dry Flue Gas Desulfurization By-Products as Amendments for Reclamation of Acid Minespoil, Proceedings of the International Land Reclamation and Mine Drainage Conference, Pittsburgh, Pennsylvania, April 24-29, p. 129-138.

Dick, W., Stehouwer, R., Bigham, J., Wolfe., Adraino, D.C., Beeghly, J., and Murarka, I., 1997, Land Application Uses of Coal Combustion By-Products: Examples and Case Studies, ASA/CSSA/SSSA Annual Meeting, Anaheim, CA, October 26-31.

Dick, W., J. Bigham, L. Forster, F. Hitzhusen, R. Lal, R. Stehouwer, S. Traina and W. Wolfe, 1998, Land Application Uses of Dry FGD By-Product: Phase 3 Report, The Ohio State University.

Hargraves, M.D., 1994, The Effect of Freeze-Thaw Cycles on the Strength of Flue Gas Desulfurization Sludge, M.S. Thesis, The Ohio State University, Columbus, Ohio.

Hite, D., Chern, W., and Hitzhusen, F., 1994, Analysis of Welfare Impacts of Landfilling Coal FGD By-Products, Proceedings of the 11th Annual Pittsburgh Coal Conference, Pittsburgh, Pennsylvania, September 12-16, p. 431-435.

Hitzhusen, F.J., 1992, Social Costs and Benefits of Recycling Coal Fired Power Plant FGD By-Products, Department of Agricultural Economics and Rural Sociology, The Ohio State University, Columbus, Ohio.

Kalyoncu, R., 1996, Coal Combustion Byproducts, US Geological Survey- Minerals Information.

Kim, S., Wolfe, W., and Wu, T., 1992a, Permeability of FGD By-Products, Proceedings of the 9th Annual Pittsburgh Coal Conference, Pittsburgh, Pennsylvania, October 12-16. p. 218-223.

Kim, S.H., Wolfe, W.E., and Hadipriono, F.C., 1992b, The Development of a Knowledge Based Expert System For Utilization of Coal Combustion By-Products in Highway Embankment, *Civil Engineering Systems*, V. 9, pp. 41-57.

Kim, S.H., Wolfe, W.E., and Hadipriono, F.C., 1993, An Intelligent Decision Support System for Embankment Design Using FGD By-Products, Symposium on Recovery and Effective Reuse of Discarded Materials and By-Products for Construction of Highway Facilities, Denver, Colorado, October.

Kim, S.H., 1994, A Decision Support System for Highway Embankment Design Using FGD By-Products, Ph.D. Dissertation, The Ohio State University, Columbus, Ohio.

Kim, S.H., Nodjomian, S., and Wolfe, W.E., 1995, Field Demonstration Project Using Clean Coal Technology By-Products, Proceedings of 11th International Symposium on Use and Management of Coal Combustion By-Products (CCBs), Orlando, Florida, Jan 15-19, American Coal Ash Association and Electric Power Research Institute, EPRI TR-104657, V. 1, p. 16(1-15).

Kost, D., Stehouwer, C., and Vimmerstedt, J.P., 1997, Initial Growth of Ground Cover and Trees on Acid Mine Spoils Treated With Wet Flue Gas Desulfurization By-Products, Sewage Sludge, and Borrow Soil, 1997 Ash Utilization Symposium, Lexington, Kentucky, October 20-22.

Mafi, S., Damian, M.T., and Baker, R., 1997, Injection of FGD Grout to Abate Acid Mine Drainage in Underground Coal Mines, 1997 Ash Utilization Symposium, Lexington, Kentucky, October 20-22.

Nodjomian, S.M., 1994, Clean Coal Technology By-Products Used in a Highway Embankment Stabilization Demonstration Project, M.S. Thesis, The Ohio State University, Columbus, Ohio.

Nodjomian, S.M., and Wolfe, W.E., 1994, Field Demonstration Projects Using Clean Coal Technology By-Products, Second Annual Great Lakes Geotechnical/Geoenvironmental Conference, West Lafayette, Indiana, May.

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Payette, R.M., W.E. Wolfe and J. Beeghly, 1997, Use of Clean Coal Combustion By-Products in Highway Repairs, *Fuel*, V.76, p. 749-753.

Roy, B.L., 1994, The Effect of Freeze-Thaw Cycling on the Resilient Modulus of Clean Coal Technology By-Products, M.S. Thesis, The Ohio State University, Columbus, Ohio.

Soto, U., Fowler, R., Bigham, J., and Traina, S., 1993, Solution Chemistry and Mineralogy of Clean Coal Technology By-Products and Mine-Spoil Mixtures, American Society of Agronomy Meetings, Cincinnati, Ohio, November 7-12.

Stehouwer, R.C., Sutton, P., and Dick, W., 1993, Growth of Fescue on Acid Minespoil Amended With FGD and Sewage Sludge, American Society of Agronomy Meetings, Cincinnati, Ohio, November 7-12.

Stehouwer, R., Dick, W., Bigham, J., Forster, L., Hitzhusen, F., McCoy, E., Traina, S. and Wolfe, W.E., 1995a, Land Application Uses for Dry FGD By-Products: Phase 1 Report, Electric Power Research Institute, EPRI TR-105264.

Stehouwer, R.C., Sutton, P., Fowler, R.K., and Dick, W.A., 1995b, Minespoil Amendment With Dry Flue Gas Desulfurization By-Products: Element Solubility and Mobility, *Journal of Environmental Quality*, V.24, p. 165-174.

Stehouwer, R.C., Sutton, P., and Dick, W.A., 1995c, Minespoil Amendment With Dry Flue Gas Desulfurization By-Products: Plant Growth, *Journal of Environmental Quality*, V.24, p. 861-869.

Stehouwer, R., Sutton, P., Dick, W., 1995d, Use of Clean Coal Technology By-Products as Agricultural Liming Materials, Proceedings of 11$^{th}$ International Symposium on Use and Management of Coal Combustion By-Products (CCBs), Orlando, Florida, Jan 15-19, American Coal Ash Association and Electric Power Research Institute, EPRI TR-104657, V. 1, p. 1(1-14).

Stehouwer, R., Dick, W., Bigham, J., Forster, L., Hitzhusen, F., McCoy, E., Traina, S. and Wolfe, W.E., 1996, Land Application Uses for Dry FGD By-Products: Phase 2 Report, The Ohio State University, Columbus, Ohio.

Stehouwer, R., and Dick, W., 1997, Soil and Water Quality Impacts of a Clean Coal Combustion By-Product Used For Abandoned Mined Land Reclamation, Proceedings of 12$^{th}$ International Symposium on Coal Combustion By-Product (CCB) Management and Use, American Coal Ash Association and Electric Power Research Institute, V. 1, p. 7(1-12).

Stehouwer, R., W. Dick, J. Bigham, L. Forster, F. Hitzhusen, E. McCoy, S. Traina and W. Wolfe. 1998. Land Application Uses of Dry FGD By-Products: Phase 2 Report. Electric Power Research Institute, Report # EPRI TR-109652.

Stewart, B., 1997, Coal Combustion Products (CCPs) Production and Use: Current Trends, 1997 Ash Utilization Symposium, Lexington, Kentucky, October 20-22.

Sutton, P., Stehouwer, R., 1992, Dry FGD By-Products as a Soil Amendment for Acidic Minespoils, Proceedings of the 9$^{th}$ Annual Pittsburgh Coal Conference, Pittsburgh, Pennsylvania, October 12-16, p. 253-258.

Sutton, P., Stehouwer, R., Dick, W.A., 1994, Mobility and liming Efficacy of Soil-Applied Dry, Alkaline FGD By-Product, American Society of Agronomy Meetings, Seattle, Washington, November 13-18.

Wolfe, W.E., Wu, T.H., and Beeghly, J.H., 1992, Laboratory Determination of Engineering Properties of Dry FGD By-Products, Proceedings of the 9$^{th}$ Annual Pittsburgh Coal Conference, Pittsburgh, Pennsylvania, October 12-16, p. 229-234.

Wolfe, W.E, and Beeghly, J.H., 1993, Truck Ramp Construction From Clean Coal Technology Waste Products, Symposium on Recovery and Effective Reuse of Discarded Materials and By-Products for Construction of Highway Facilities, Denver, Colorado, October.

Wolfe, W.E., Cline, J.H., 1995, A Field Demonstration of the Use of Wet and Dry Scrubber Sludges in Engineered Structures, Proceedings of 11$^{th}$ International Symposium on Use and Management of Coal Combustion By-Products (CCBs), Orlando, Florida, Jan 15-19, American Coal Ash Association and Electric Power Research Institute, EPRI TR-104657, V. 1, p. 17(1-10).

Wolfe, W.E., Butalia, T.S., and Meek, B.L., 1997, Influence of Freeze Thaw Cycling on Resilient Modulus of Clean Coal Technology By-Products, 1997 Ash Utilization Symposium, Lexington, Kentucky, October 20-22.

Wolfe, W.E., and Butalia, T.S., 1998, Use of FGD as an Impervious Liner, 23rd International Technical Conference on Coal Utilization and Fuel Systems, Clearwater, Florida, March 9-13.

Wolfe, W.E., Butalia, T.S., and Fortner, C., 1999, Preliminary Performance Assessment of an FGD-Lined Pond Facility, 13th International Symposium on Management and Use of Coal Combustion Products (CCPs), Orlando, Florida, January 11-14.

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